



PDV measurements on the Sandia Z machine

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Sandia National Laboratories

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Overview

- **Making PDV work at Z**
 - System capabilities
 - Frequency-shifted measurements
- **Single- and multi-point measurements of cylindrical implosion**
 - Liner studies
 - Liquid-filled liners
- **Planar impact experiments**
 - High speed flyers
 - Shock front measurements





Making PDV work at Z



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System capabilities

- **Electrical bandwidth**

- Eight 20 GHz receivers recorded with 25 GHz digitizers at 80 GS/s
 - Covers up to 19.4 km/s

- **Lasers**

- One amplified laser (space limited)
 - Tunable seed + EDFA or 2 W system at fixed wavelength
- Several adjustable reference lasers (25-50 mW output)
 - Fast tuning over 1550-1551 nm
- Leapfrog is temporarily disabled in favor of multi-point measurements

- **Other**

- Wavelength monitoring to ~ 0.1 pm
- Timing characterization
 - $\ll 100$ ps uncertainty between PDV channels
 - ~ 200 ps uncertainty to machine time



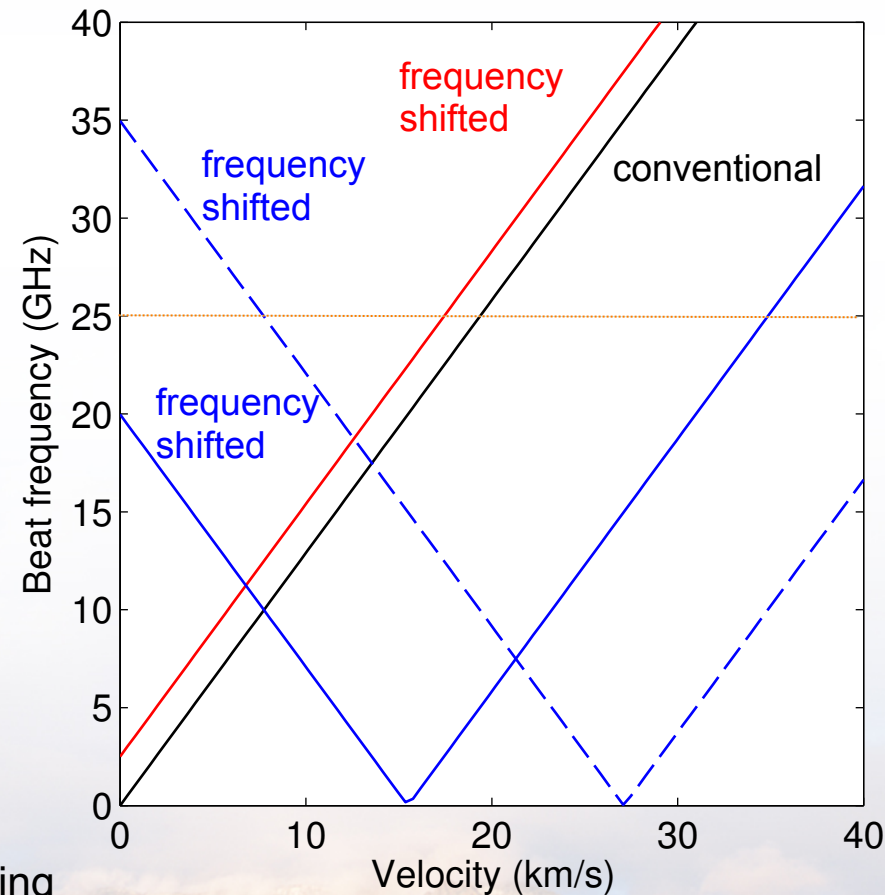
Velocity-frequency mapping

- **Conventional** $B = \frac{2v}{\lambda_T}$
 - No motion, no beating
 - Not currently used at Z

- **Frequency shifting**

$$B = \left| \frac{2v}{\lambda_T} + c_0 \left(\frac{1}{\lambda_T} - \frac{1}{\lambda_R} \right) \right|$$

- **Red reference**
 - Unambiguous mapping
 - Preferred configuration
- **Blue reference**
 - Greater coverage
 - Issues near $f=0$
 - May require precise wavelength monitoring

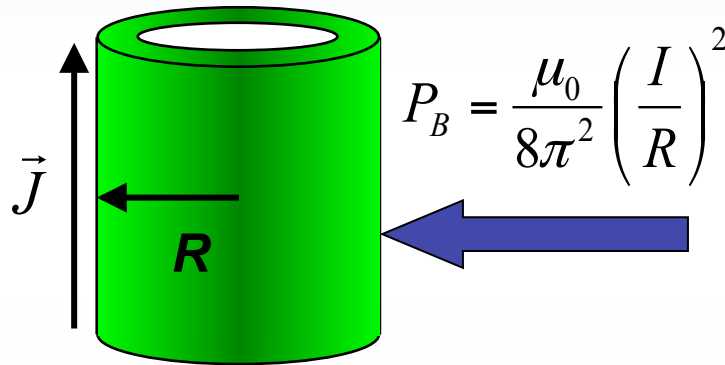




Cylindrical implosion

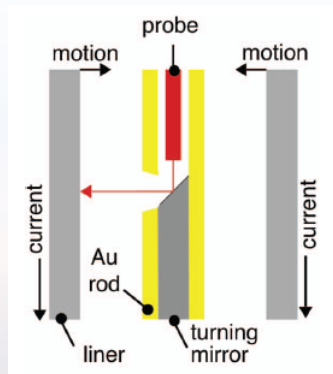
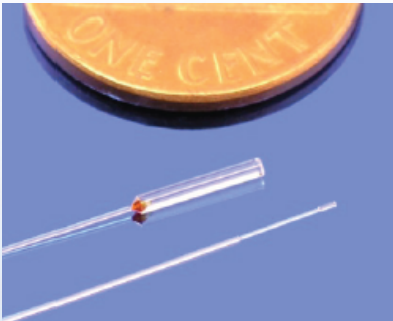


Cylindrical implosion reaches extreme pressure states



$I=20$ MA
 $R=0.1$ cm
 $P_B \approx 64$ Mbar

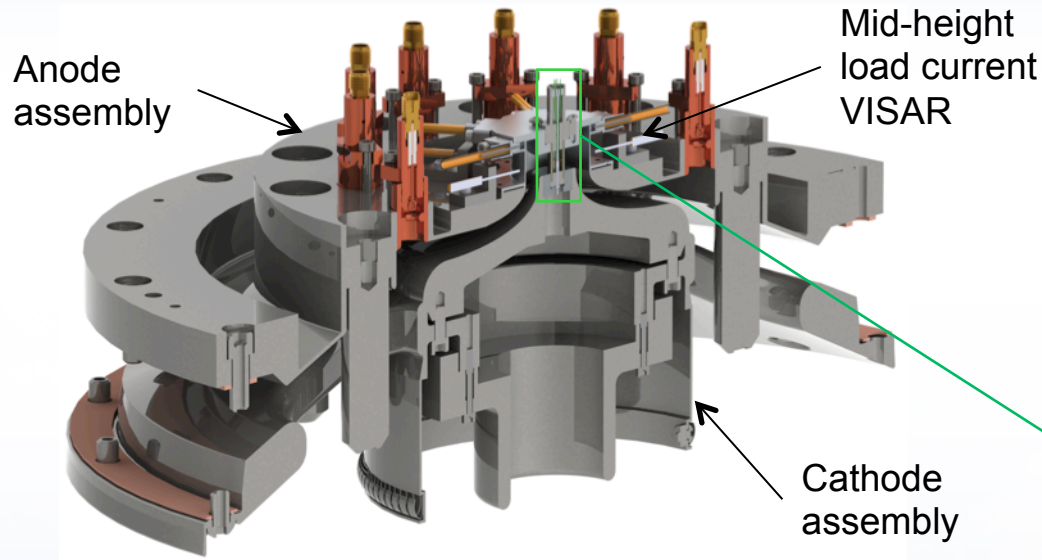
- **Current pulse shaping creates ramp-wave compression**
 - Quasi-isentropic compression to 20 Mbar



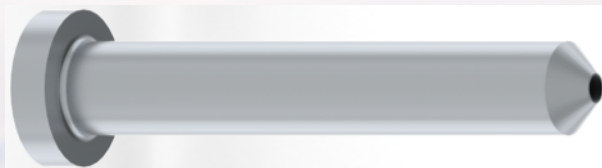
Diagnostics are challenging

- **Limited space**
 - Miniature PDV probes
- **Velocities well beyond 10 km/s**

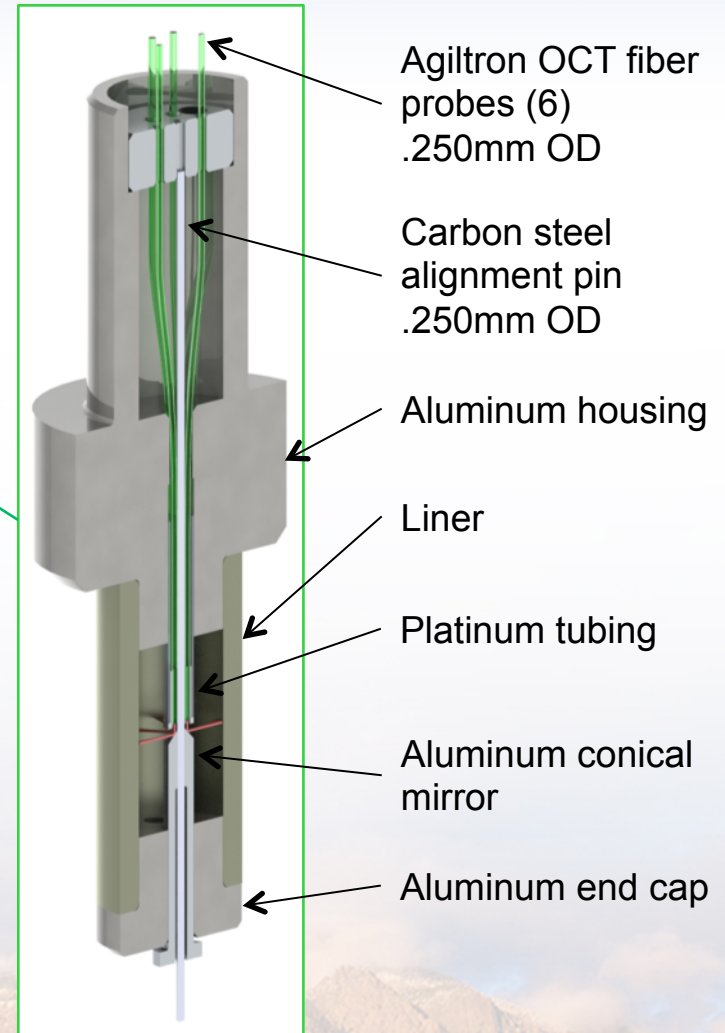
Multi-point design evaluates symmetry



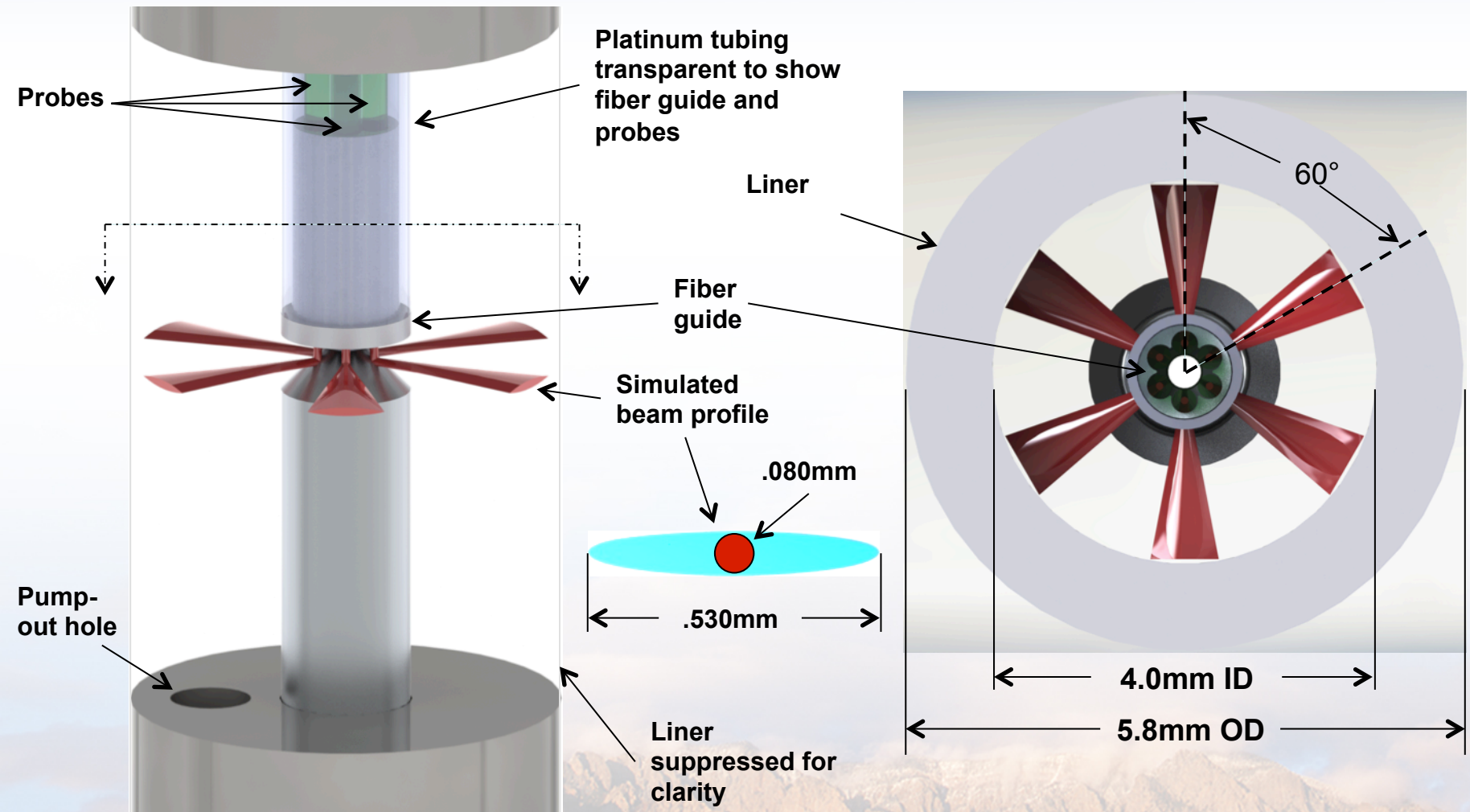
- ≈ 18.6 MA Load Current
- 10-20 km/s velocity (heavier liners)



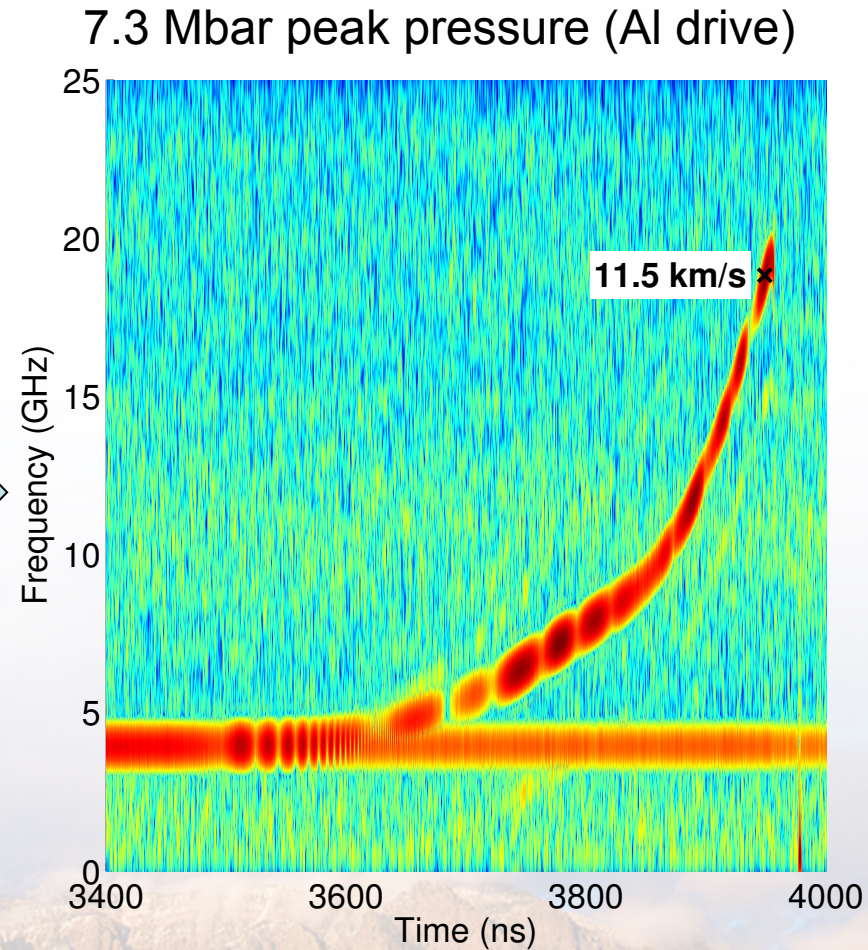
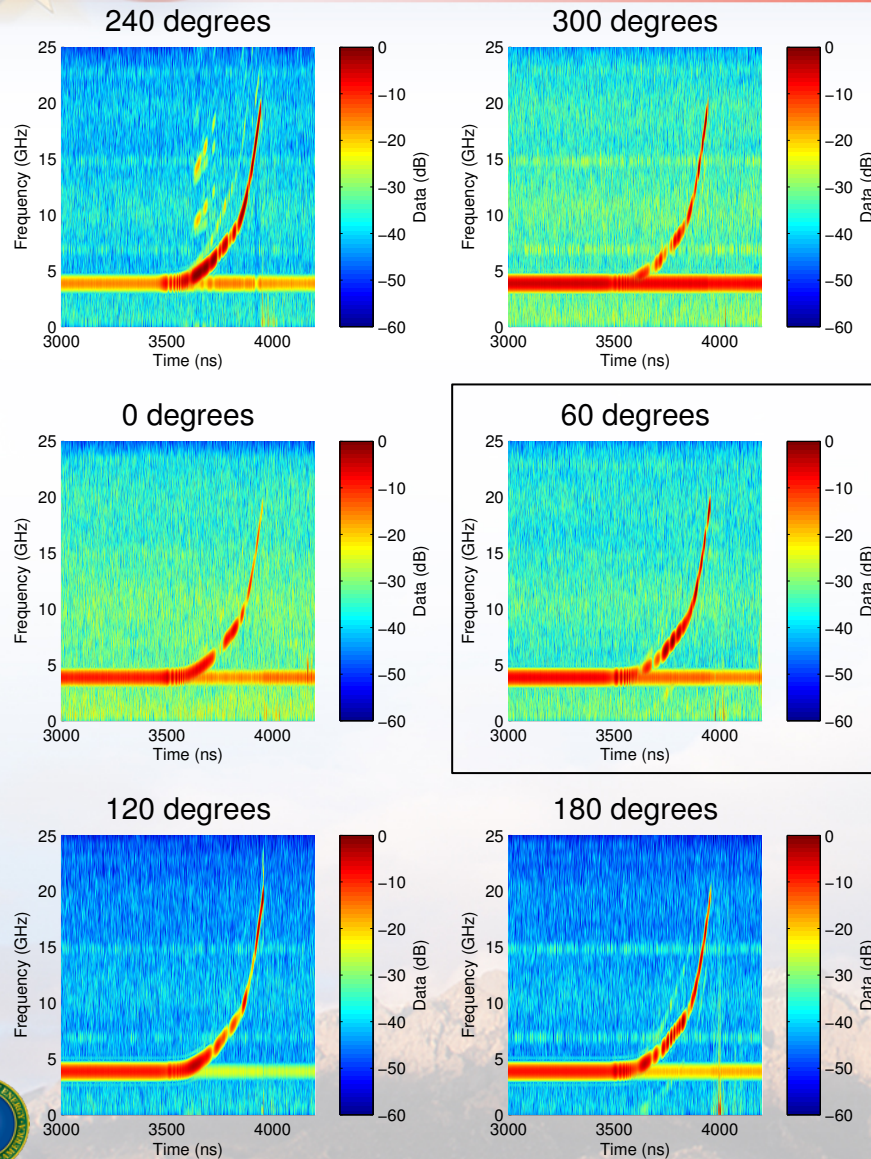
Conical mirror
design



Measurements every 60 degrees



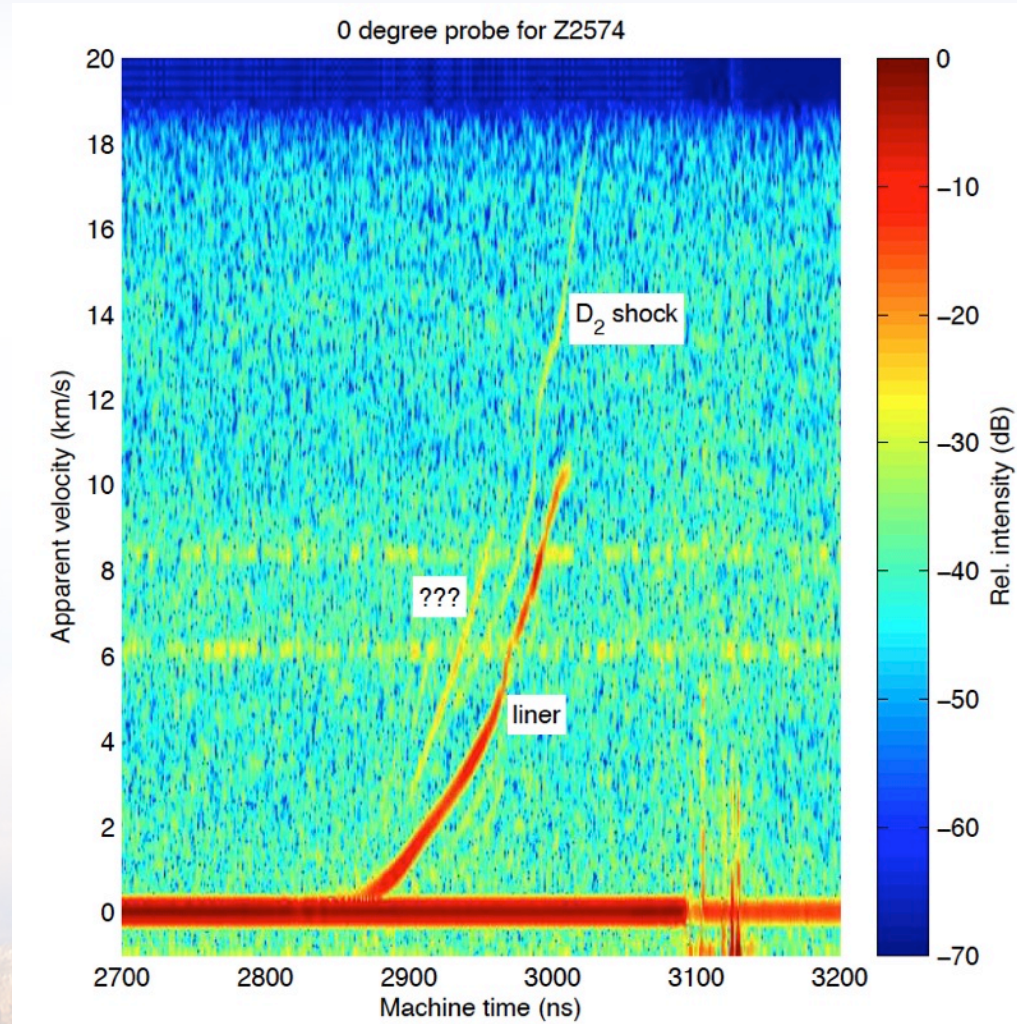
Symmetric results for Ta



Hollow liner can be filled with a liquid

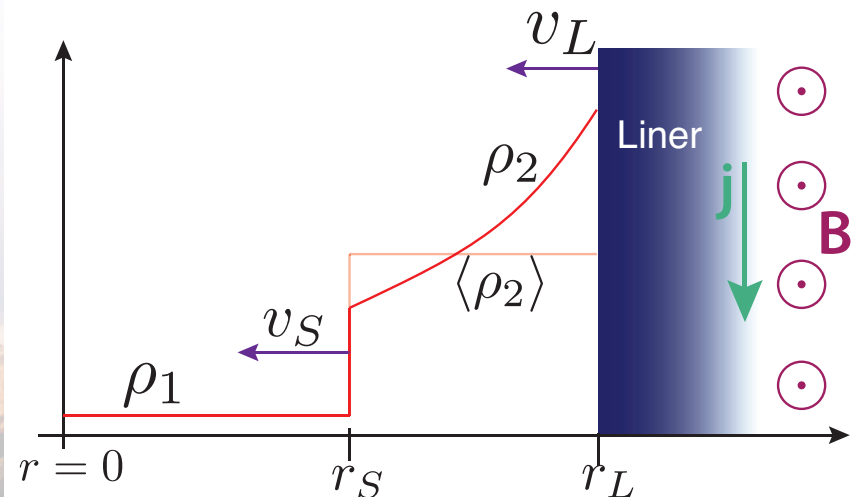
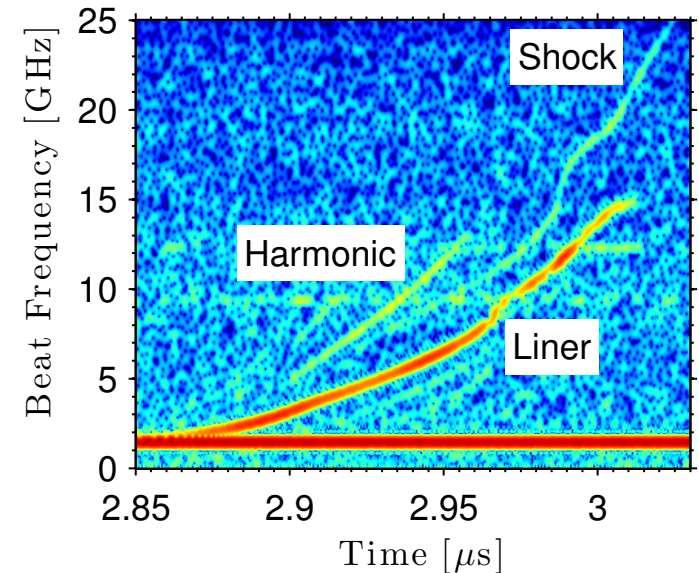
- **Eddy series:**

- Beryllium liner filled with liquid deuterium (4 K)
- Probe immersed in liquid
 - Survives condensation
 - Some fibers damaged during freeze/melt cycle
- “Chandelier” design
 - Conical mirror incorporated into the probe bundle
 - X-ray radiography performed underneath the PDV measurement



Eddy interpretation

- **Magnetic drive launches a ramp wave in the liner**
- **Ramp wave quickly becomes a shock wave in the liquid**
 - Liner reflection
 - Shock shock (initially weak)
- **As the shock grows stronger, its reflectance increases**
 - Eventually light cannot reach the liner
- **Window corrections are complicated**
 - Ambient index unknown
 - No steady state





Planar impact



Planar impact measurement

- **Glow Discharge Polymer (GDP)**

- NIF ablator material
- Very little Hugoniot data

- **Ideal experiment**

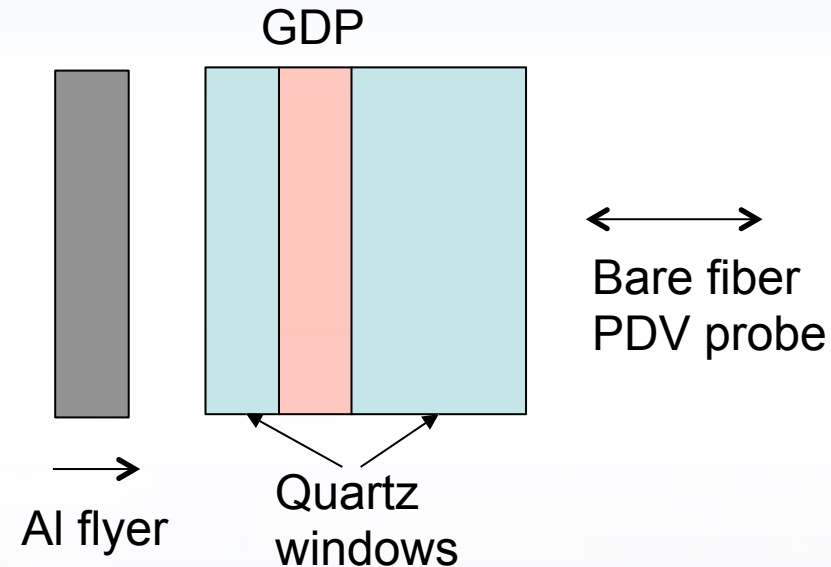
- Measure flyer velocity
- Measure GDP shock velocity
- Impedance match GDP to the flyer

- **Real experiment**

- Sample sealed between quartz windows to prevent oxygen absorption
- Impedance match to the front quartz window

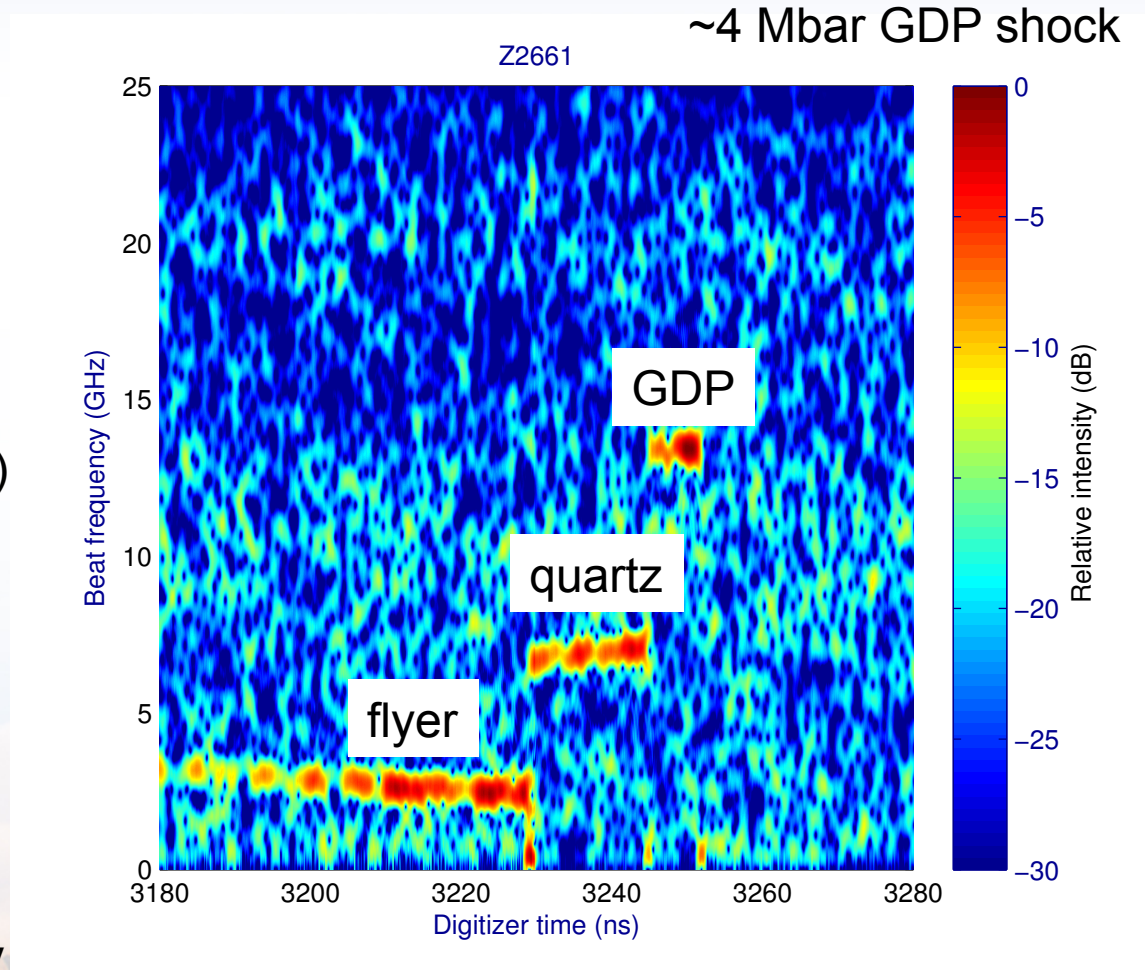
- **Characteristic velocities**

- Flyer: 25 km/s
- Shock: 20-30 km/s (apparent velocity ~50% higher)



GDP results

- **Offset frequency**
 - 35.148 ± 0.006 GHz
 - 27.257 ± 0.005 km/s
- **Flyer measurement**
 - 2.44 GHz beat
 - ~ 25.4 km/s (before bounce)
- **Quartz measurement**
 - 6.7-7.2 GHz beat
 - 32.5-32.9 km/s apparent velocity (after bounce)
- **GDP measurement**
 - 13.4 GHz beat
 - 37.6 km/s apparent velocity (after bounce)





Future work

- **Probe development**

- Specular reflections are common (DT surfaces, shock fronts)
- Very little orientation control, almost no optimization possible
- Must be very small (ideally <1 mm diameter)
- <1 mm to 10-20 mm working distances
- Desired return losses: 30-50 dB

- **Multi-channel leapfrog support**

- Eight channels with four-way leapfrog coming online later this year
- Support velocities up to 81 km/s using only two digitizers (8 detectors)

- **Improved analysis capabilities**

- Extended baseline management
- Multiple peak capabilities





Special Thanks

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